Progress of the CEPC scintillator-tungsten ECAL

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On behalf of CEPC calorimeter working group

Outline

- Introduction of CEPC scintillator-tungsten ECAL
- Scintillator module test and optimization
- Design and development of readout electronics
- Single layer prototype construction and test
- Summary

Requirements of CEPC ECAL

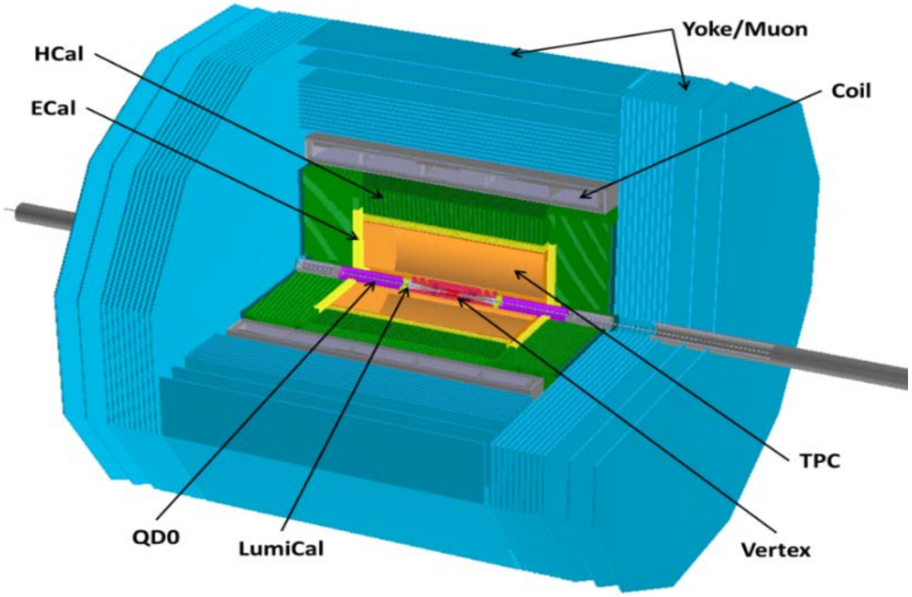
- Precise measurements of electrons and photons with energy resolution of :

  $\sigma_E/E \approx 16\%/\sqrt{E} \oplus 1\,\%$

- Jet energy resolution (ECAL combined with HCAL and tracker):

  $\sigma_E/E \approx (3\% - 4\%)$

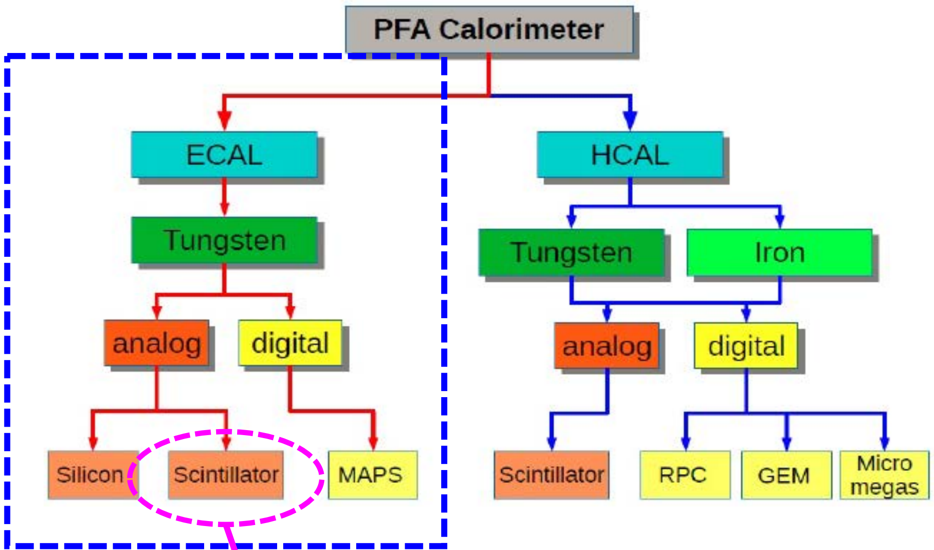
- Can give detailed information of showers: high granularity



Particle Flow Algorithm (PFA) calorimetry system is considered

- High granularity
- Compact showers(small radiation length X_0, and small Moliere radius R_M)
- Minimum dead materials
- Good energy resolution

Scintillator-tungsten ECAL



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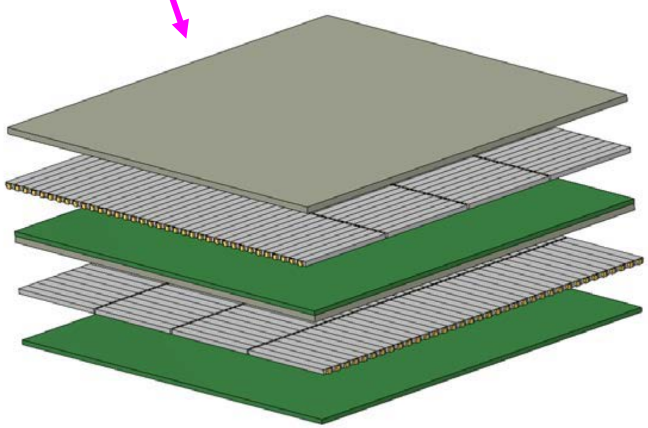
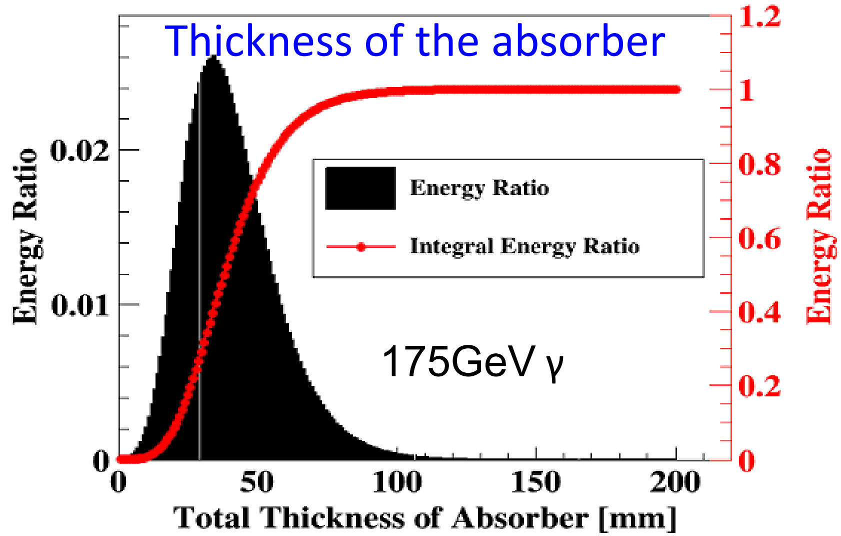
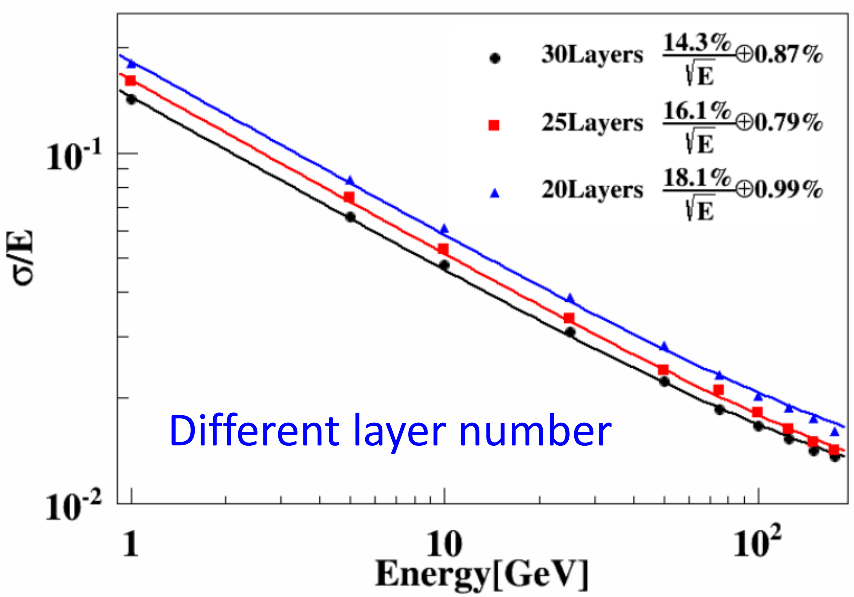


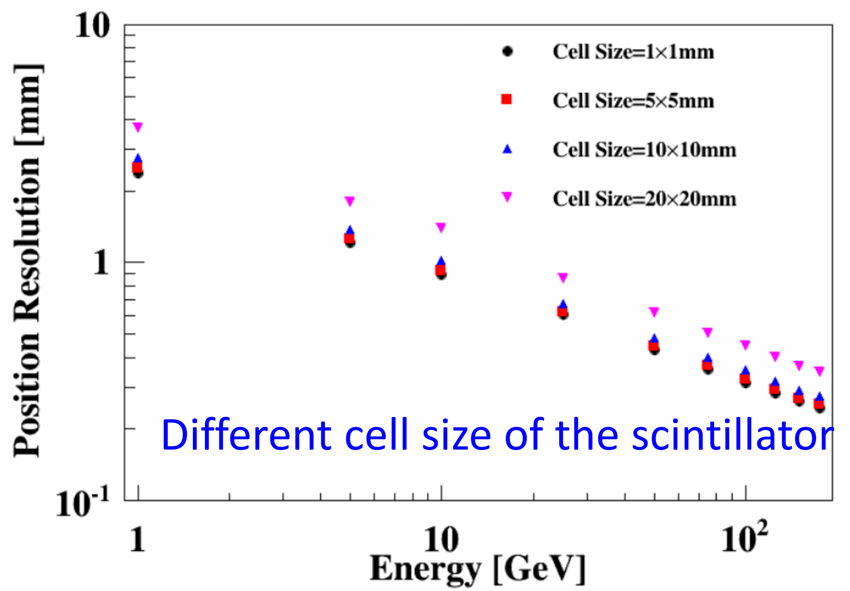
- A sampling calorimeter with scintillator-tungsten sandwich structure (ScW) is one of the ECAL options
- A R&D programme supported by Ministry of Science and Technology of China (MOST)
- Sandwich structure
  - Absorber + scintillator module + readout electronics(PCB)
- Scintillator readout module
  - Scintillator + SiPM
- Absorber
  - Tungsten

Optimization of ScW ECAL

- The key parameters were studied by simulation and optimization of the structure and geometry
  - Total thickness of the absorber: 80~90mm
  - Layer number: 25-30
  - Granularity: about 5mm × 5mm
  - Thickness of the scintillator: 2mm

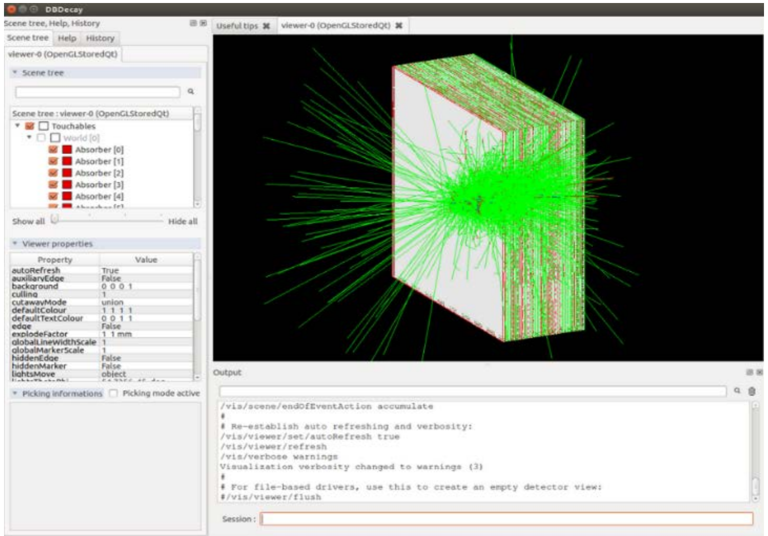


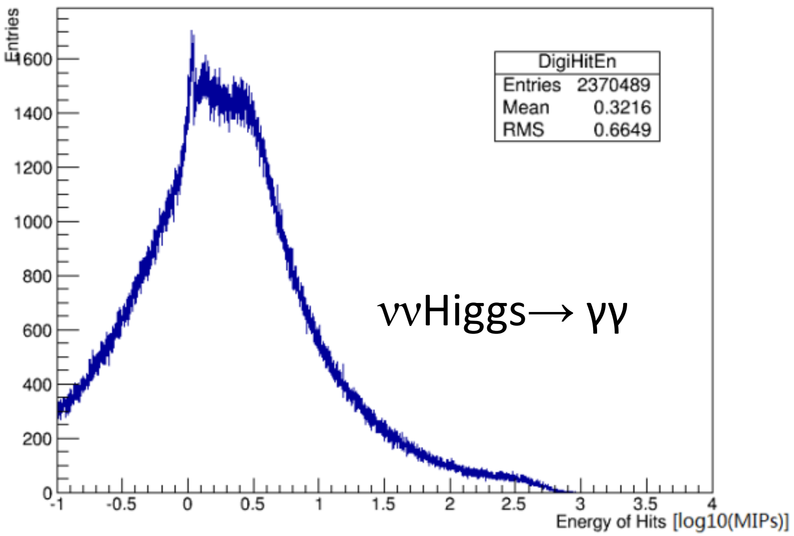


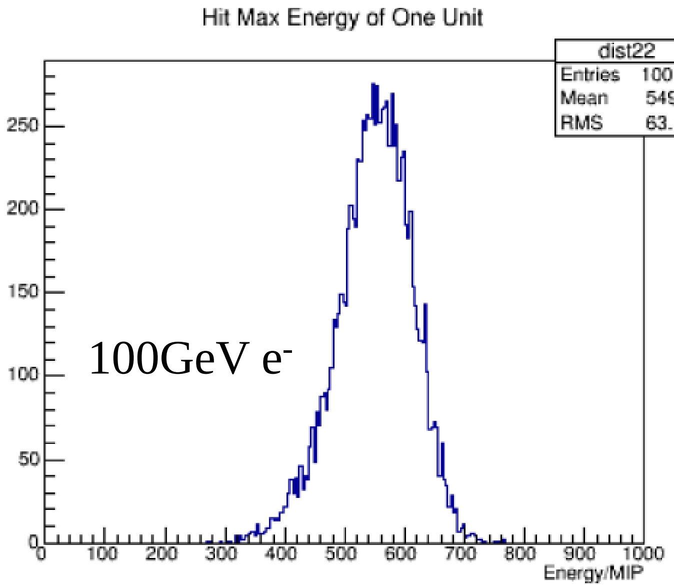


ECAL Optimization II

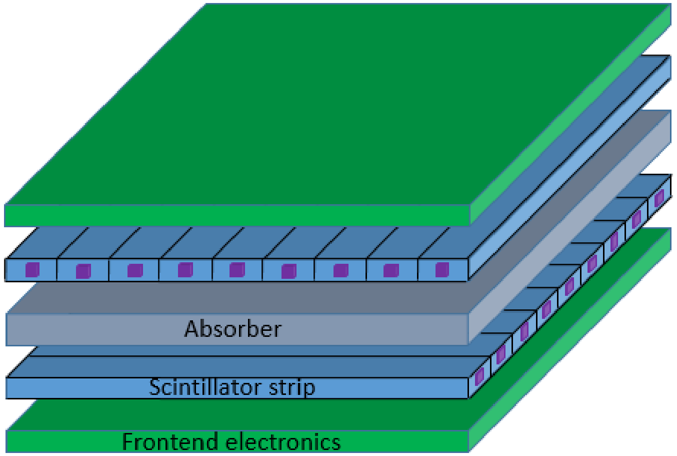
- Dynamic range of ECAL scintillator module
  - 1MIP – ~800 MIPs
- ~15 p.e. @ 1 MIP
  - SiPM >10k pixels

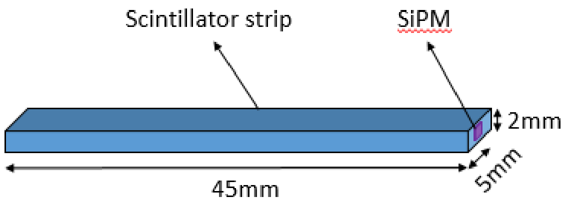






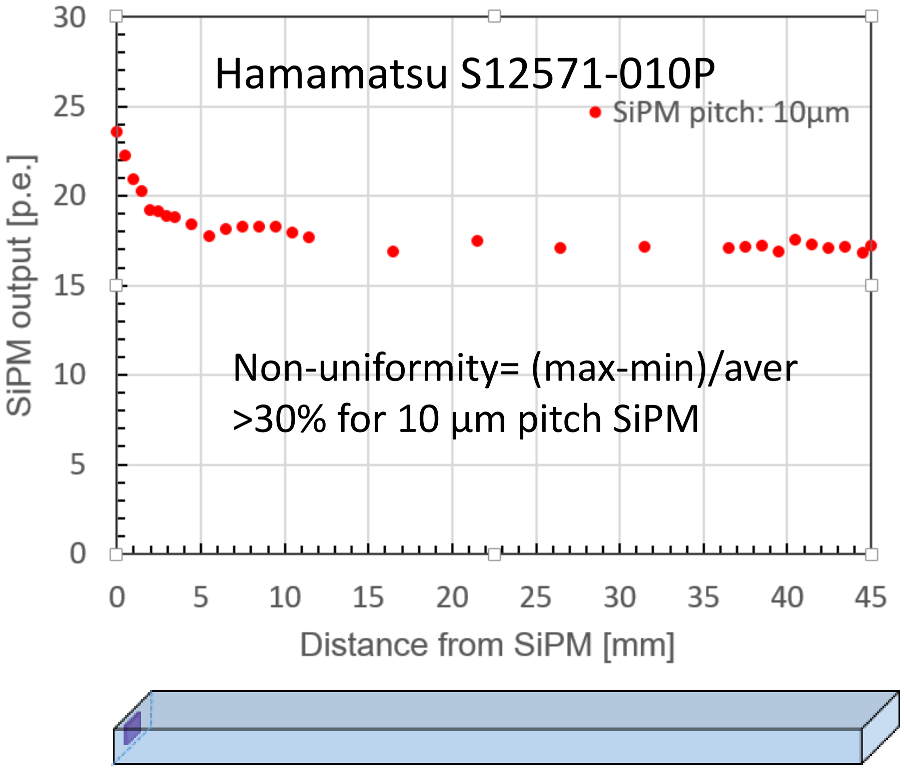
Scintillator module

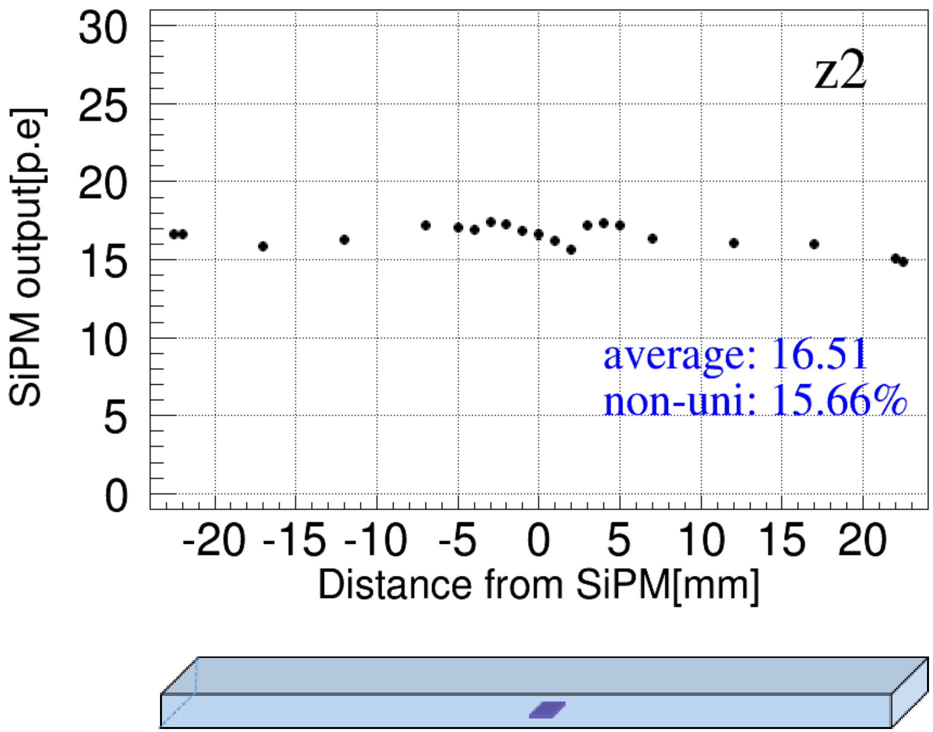




- The scintillator module : Scintillator wrapped with reflector+ SiPM
- The key parameters: Granularity, Light output, Homogeneity, Dynamic range, Dead material /area
- Scintillator dimension : 5mm×45mm×2mm
- Cross arrangement of neighboring layers → a transverse readout cell size of 5×5 mm^2
- Reduction of the readout channels → low cost
- SiPM coupled at the side or the bottom of the scintillator strip → few or negligible dead area

Module test and optimization





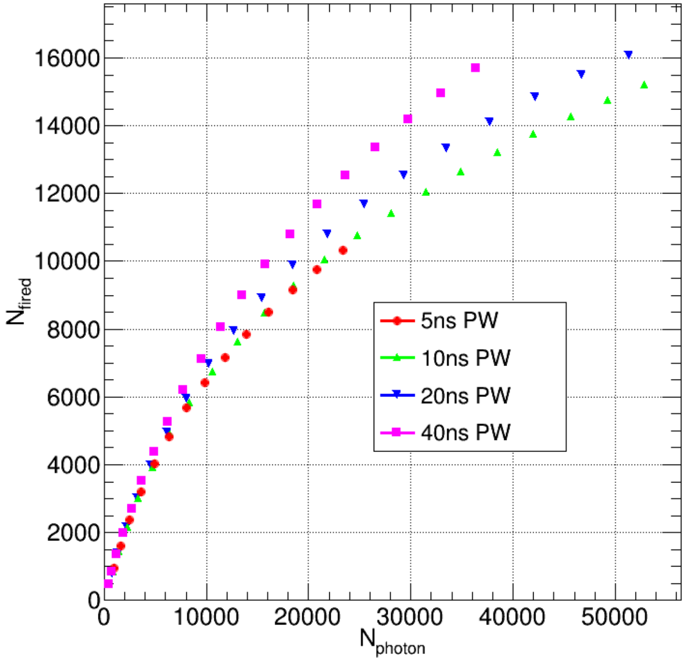
- At the beginning, SiPM (Hamamatsu S12571-010P) coupled at the side-end of the scintillator ⟶ bad uniformity
- Change the coupling mode: SiPM embedded at bottom-center of the strip
- Uniformity of light output is improved significantly

SiPM bottom-center embedded coupling

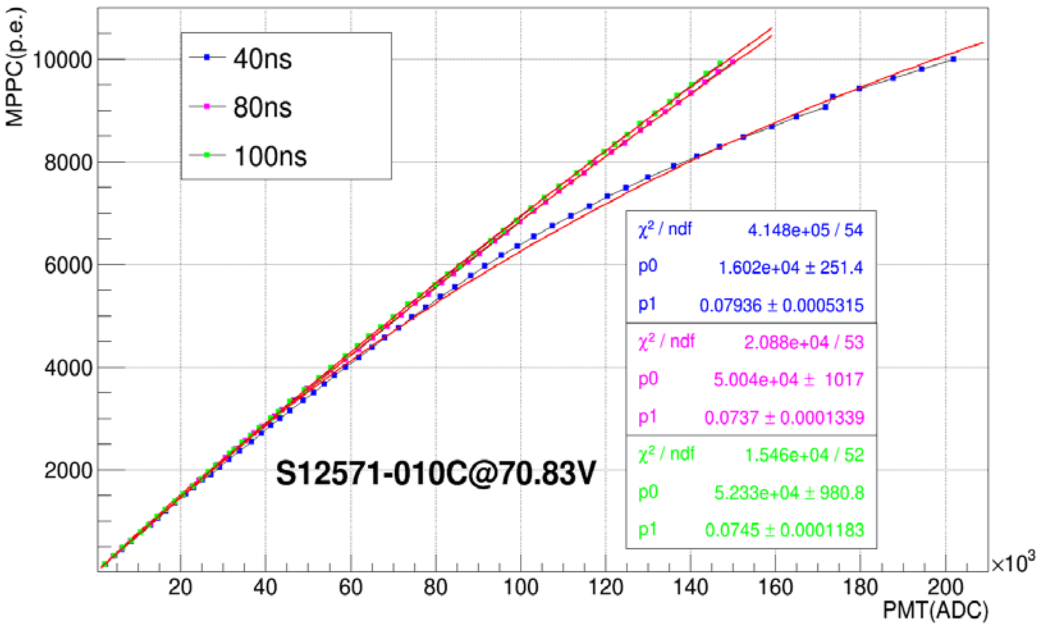
SiPM bottom-center embedded coupling mode will be adopted in the construction of the ScW ECAL prototype

- Improve the uniformity → The non-uniformity can reach about 15%
- No gap between the scintillators → Avoid the dead area
- Easy to operation in the prototype construction
- Enabling to extend the SiPM area with more pixels and extend the dynamic range of the SiPM

SiPM linearity and dynamic range



The width of LED light are: 5ns - 400ns

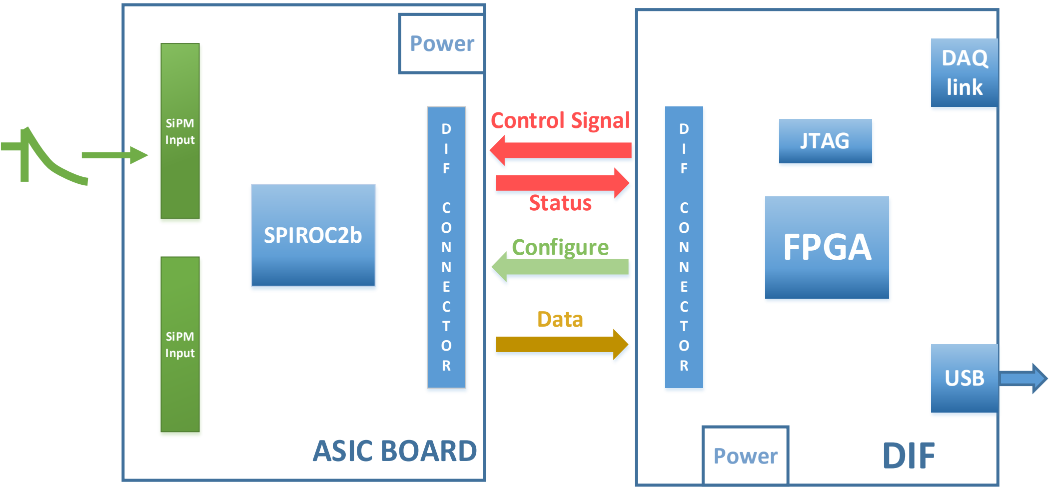


- The SiPM output linearity and effective pixels are improved with the incident light width
- SiPM response can be described well with the theoretic formula

$\boldsymbol{N_{fire} = N_{eff}(1 - e^{-\epsilon N_{in}/N_{eff}})}$, Nfire: number of fired pixels, Neff: number of effective pixels, Ɛ : PDE, Nin : number of incident photons.

- Saturation effect could be corrected

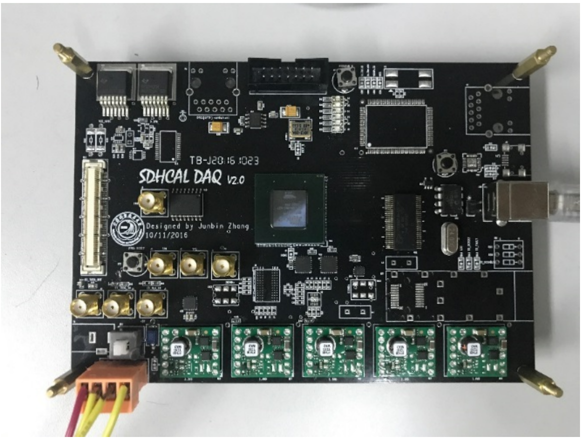
Electronics Development



System schematic

- Asic board is developed with **SPIROC2b/SPIROC2e** chip, which performs amplification, auto-triggering, digitization and zero-suppression
- DIF initializes chips and collects data
- USB for data upload & commands sending
- USB for single DIF, and **serial port for DAQ** when using multiple DIF

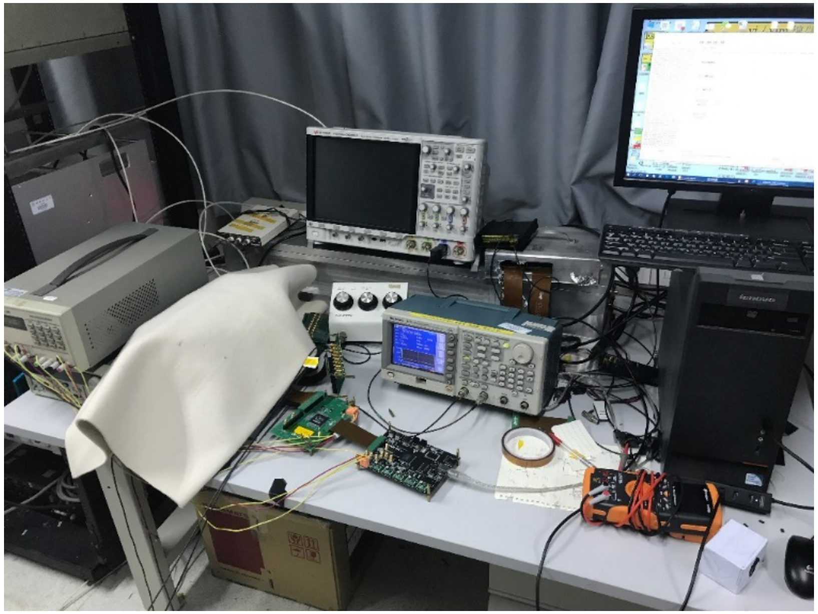
FEB



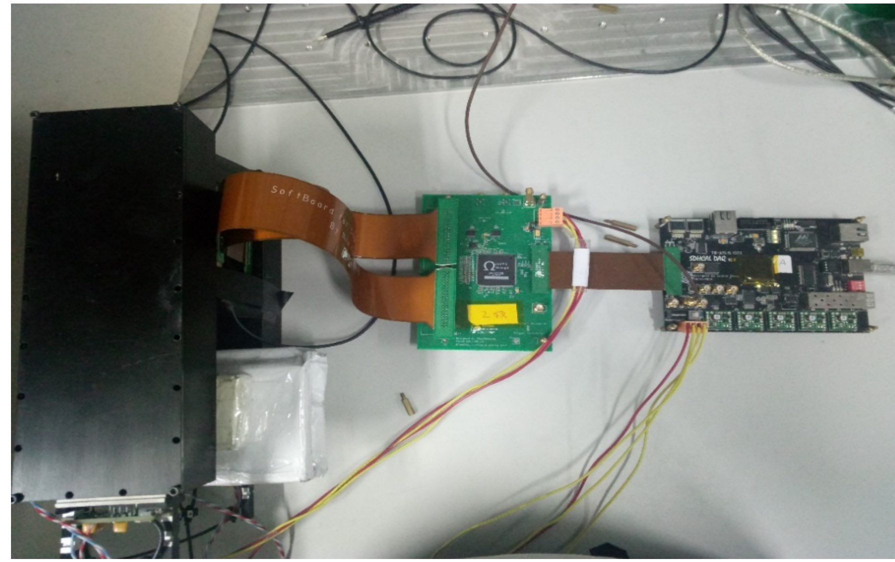
DIF

- Switched capacitor array store charge measurement
- 12 bits ADC conversion
- Variable Gain due to:
  - adjustable Cf of pre-amplifer
  - Rload on the board
  - Shaping time and delay

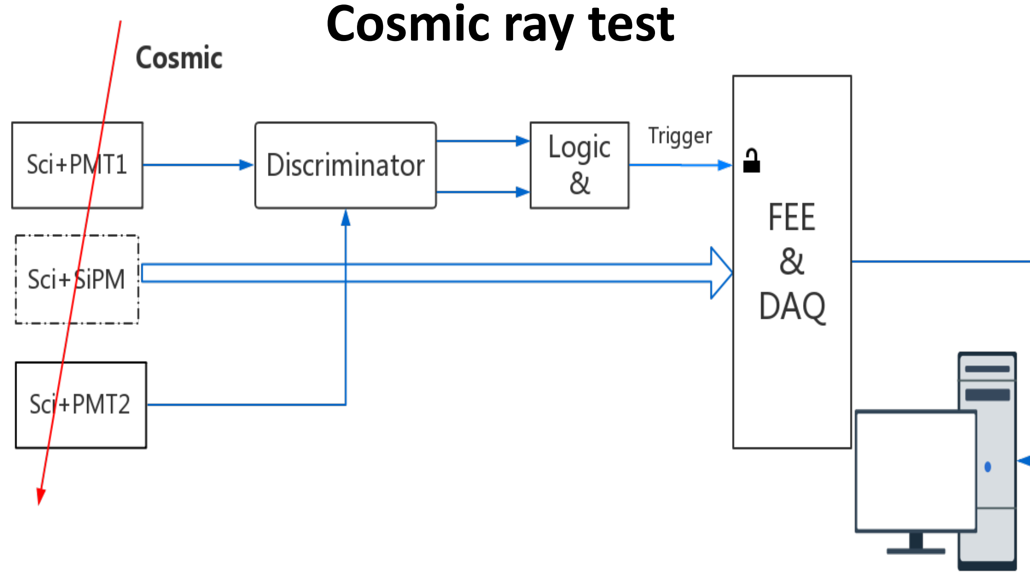
Electronics test



Test Platform



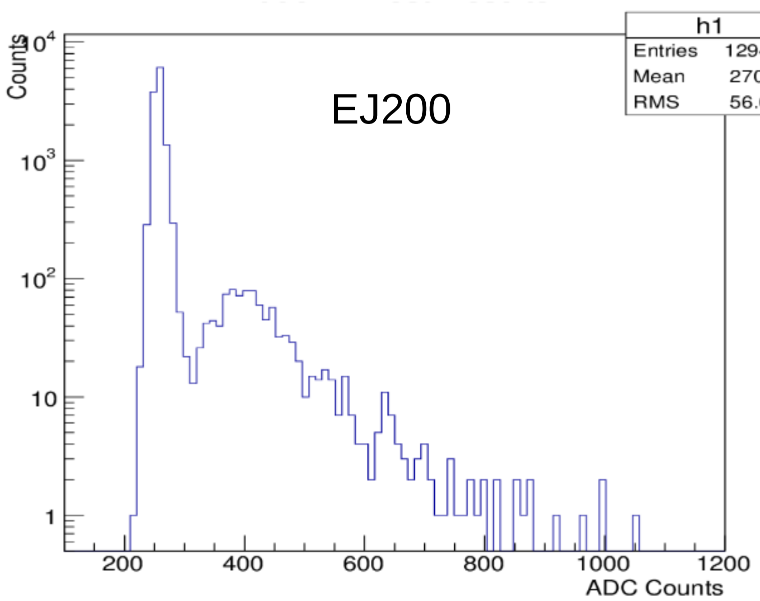
Cosmic ray test

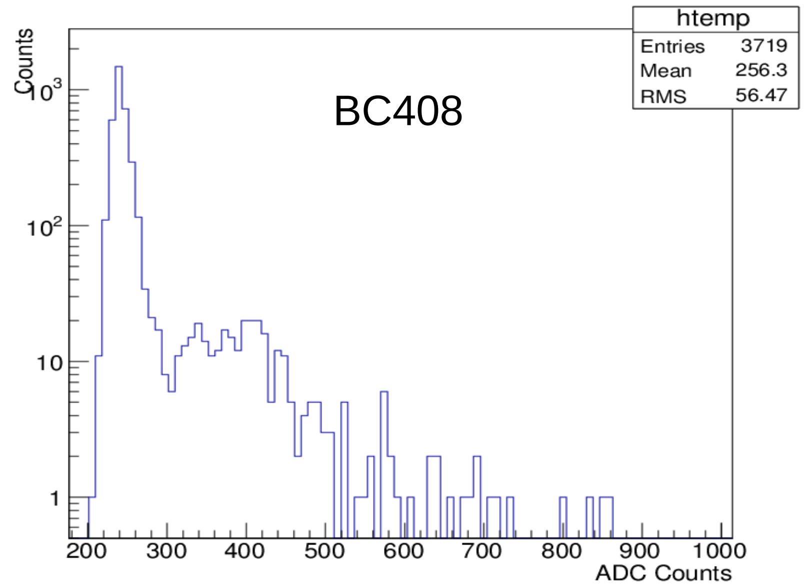


- Calibration
- Cosmic-ray test with scintillator modules

Electronics cosmic-ray test

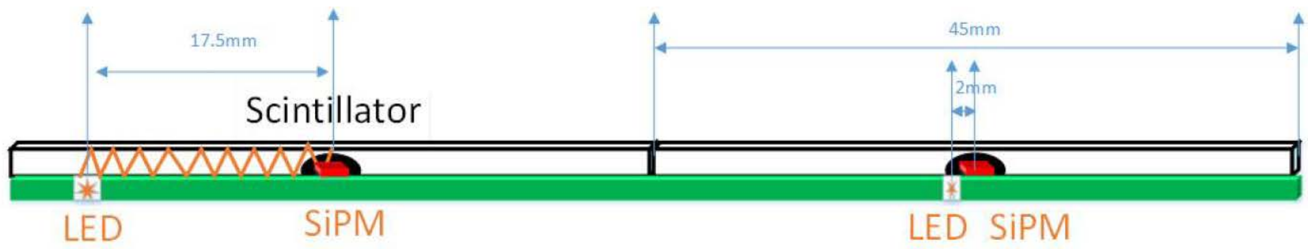
- Different scintillators were tested by cosmic rays
  - Plastic scintillator: BC408, EJ200
  - SiPM: S12571-010P with dimension of 1mm × 1mm and 10k pixels

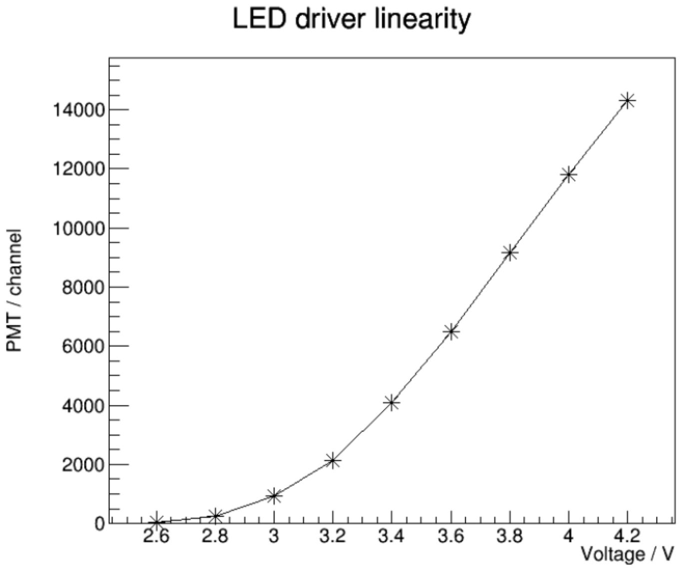




- The peak of the MIPs is clearly separated from the pedestal
- The electronics worked with good performance

Preliminary design of the calibration system



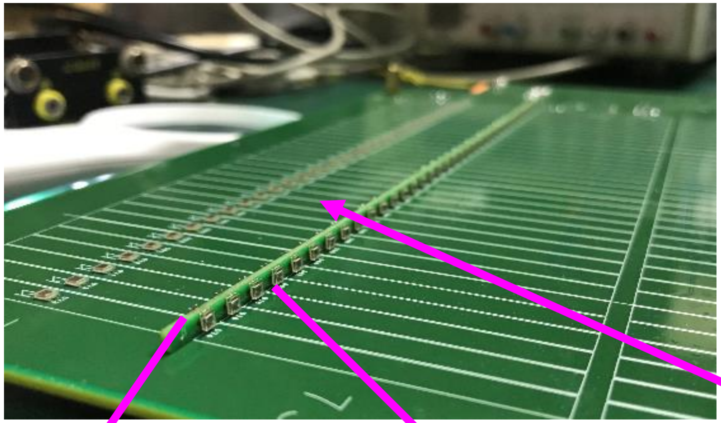


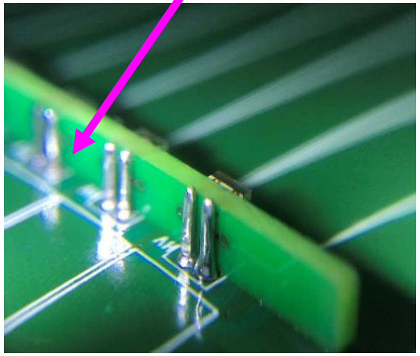
- Single photon-electron can not be used to calibrate each scintillator modules with For S12571-010P SiPM, due to big electronics noise with **SPIROC chips**
- **LED calibration system is considered and designed**

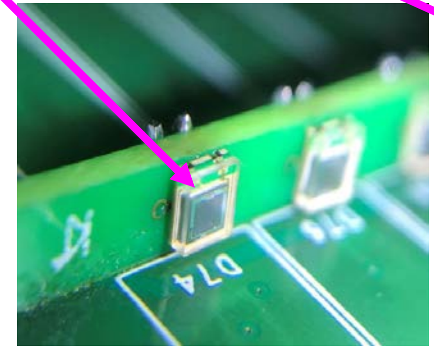
Preparation for single layer prototype

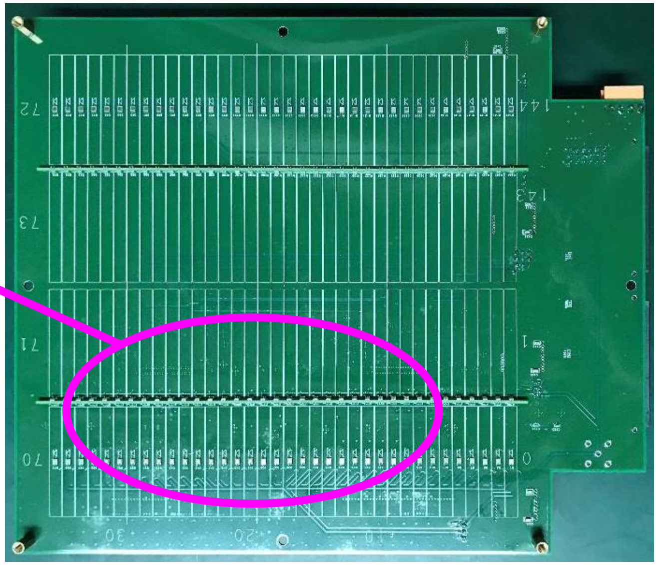
- Single layer prototype for the study of module layout, integration, preliminary performance
- 4 SPIROC2b chips, 144 modules
- Half : side-end coupling mode, another half : bottom-center embedded coupling mode

Front End Board



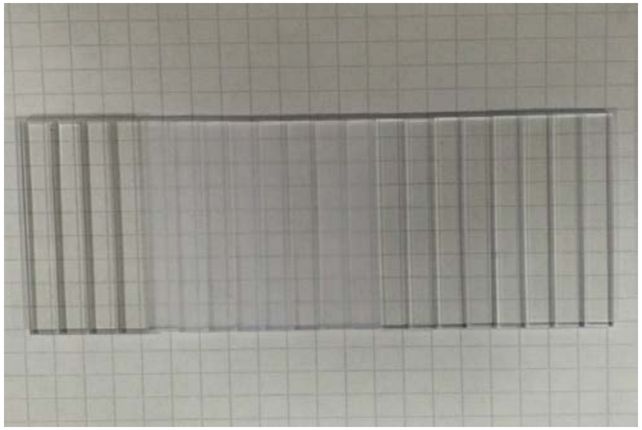


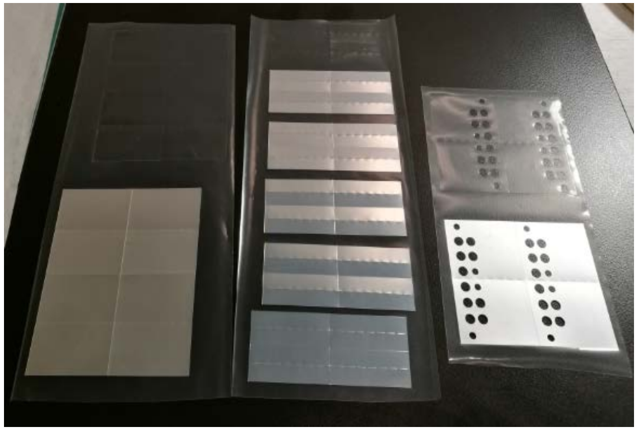


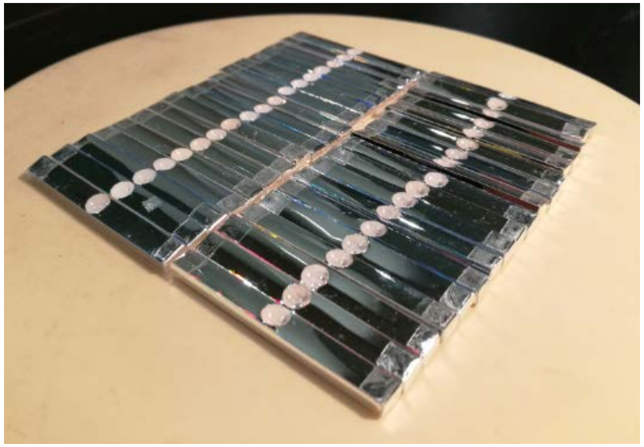


Scintillator modules

Cutting → Grooving → Polishing → Annealing → Cleaning → Packing



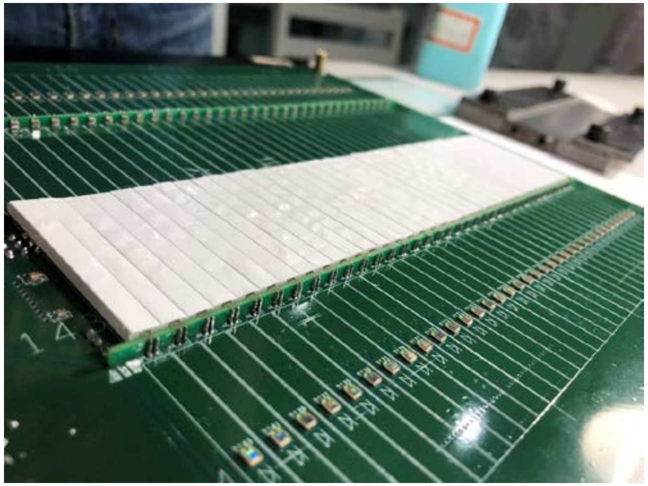


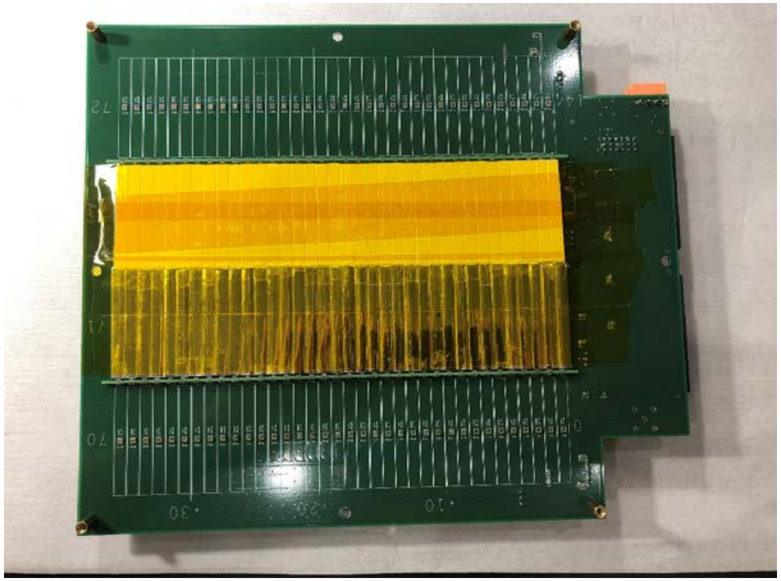


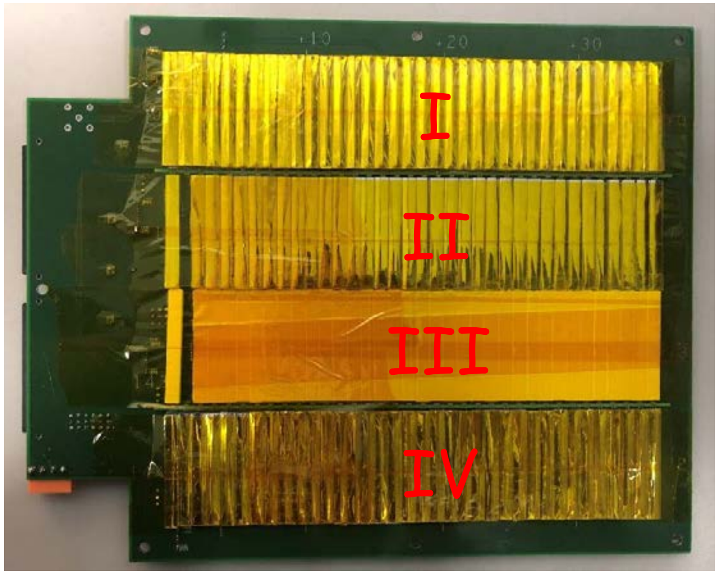
Scintillator strips are incised and wrapped in the SIC (Shanghai Institute of Ceramics)

Assembly

- 144 modules of scintillator strip coupling with SiPM (S12571-010P)
- I and IV: bottom-center embedded coupling mode, wrapped with ESR
- II: Side-end coupling mode scintillators wrapped with ESR
- III: Side-end coupling mode scintillators wrapped with Teflon

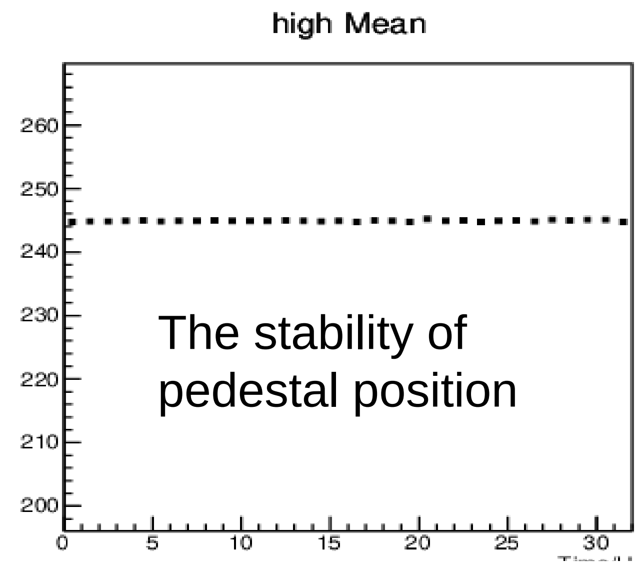


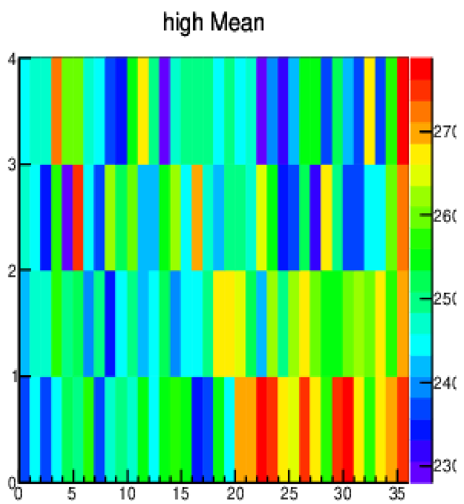


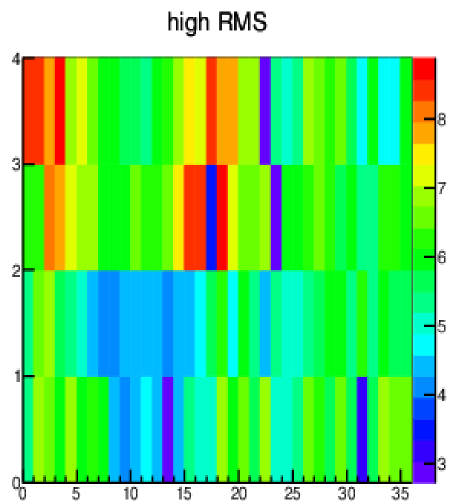


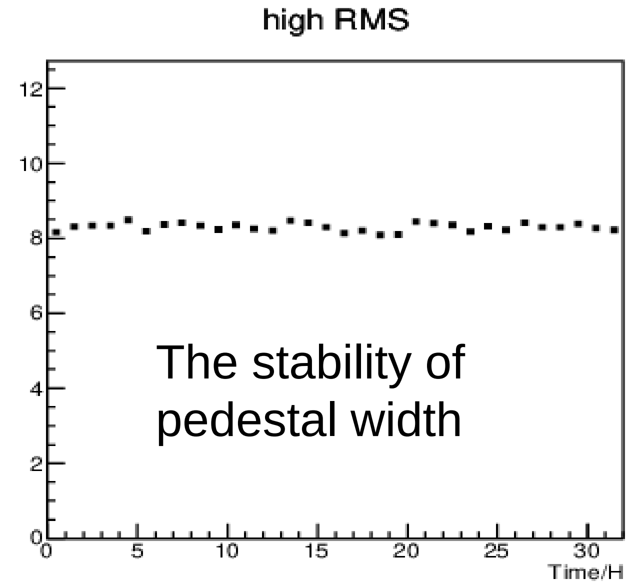
Pedestal of single layer

- Working in high gain mode
- SiPM with H.V.
- Long time work stability

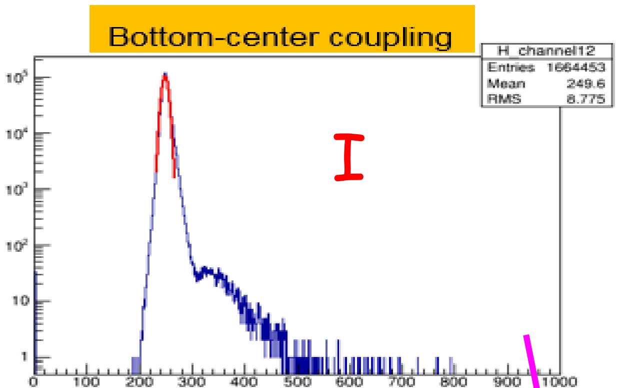


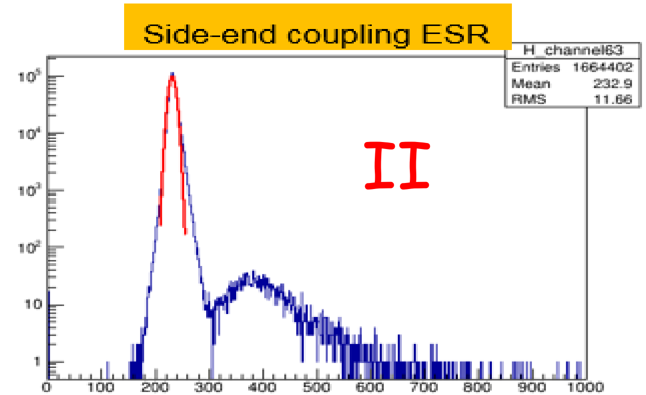


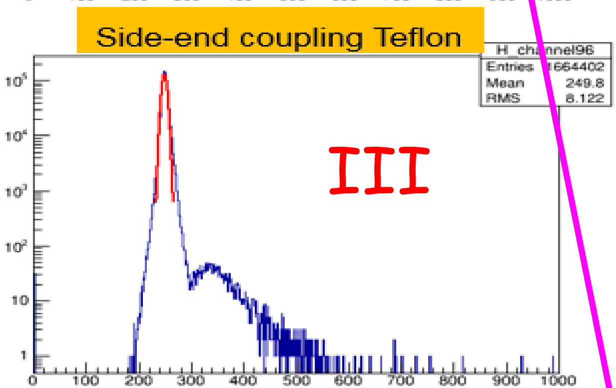


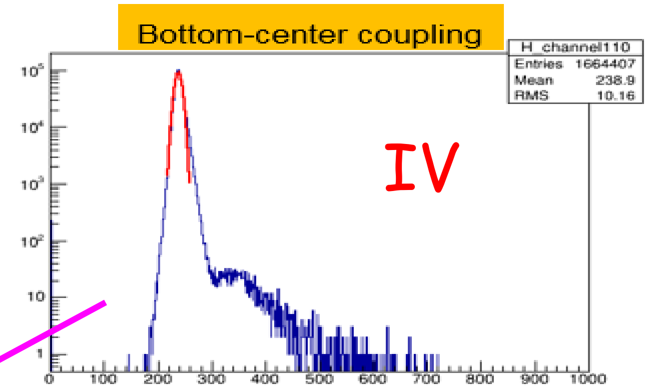


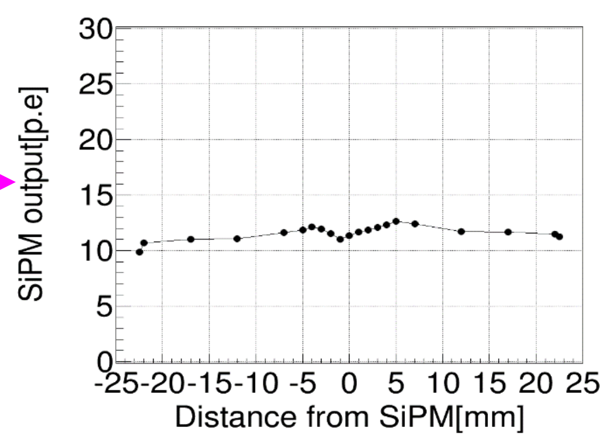
Cosmic-ray test





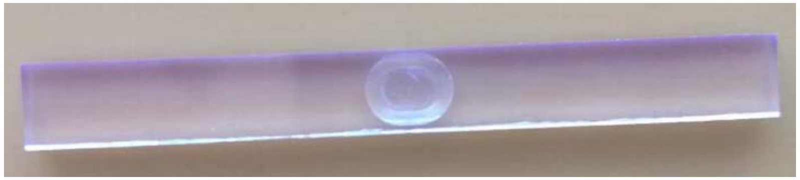


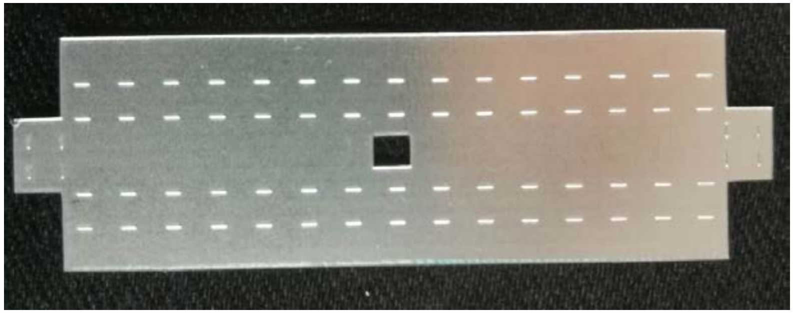


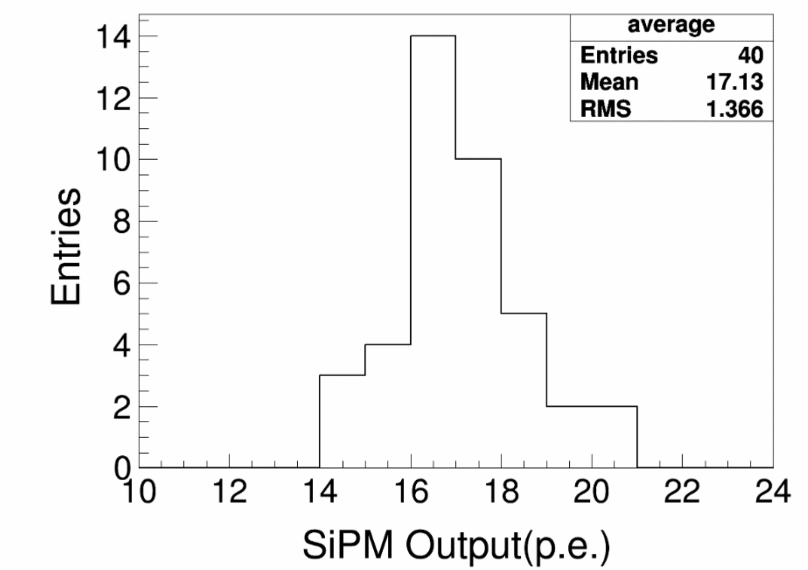


- Small cracks lead to low light output

New scintillator strips







Summary

- Scintillator strip modules were tested and optimized
- Readout electronics was designed and developed
- A single layer prototype was constructed and test with cosmic-ray
- New scintillator module will be prepared to replace the old ones on the single layer prototype

Thanks for your attention !